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Selection of Structural Analysis Computer Programs

by

L.V. Andrew and I.C. Taig

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Report No. 670

6 SELECTION OF

STRUCTURAL ANALYSIS COMPUTER PROGRAMS

by

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PREFACE

The use of computerised techniques of structural analysis is now standard in many branches of engineering. There is, however, a wide range of programs available both commercially and within individual organisations. These programs differ in their capabilities and in their costs and ease of use. The potential user may experience considerable difficulty in selecting a program that is appropriate to his particular class of work.

An Ad Hoc Group to consider this problem was established by the Structures and Materials Panel at its 45th Meeting. Following discussions at the 46th Meeting in Aalborg, Denmark, it was decided to invite the presentation of specialist Pilot Papers to give guidance to both the Panel and to users. The papers, that were subsequently presented at the 47th Meeting in Florence, Italy, by Mr Andrew and Mr Taig were judged to be of such general interest that they warrant wide distribution.

The paper by Mr. Andrew describes in detail the technical and administrative course of action that has been adopted by a major industrial organisation to select and implement programs that are appropriate to its work. Mr Taig presents a similar discussion but with perhaps more emphasis on technical issues.

Since many of the essential elements of the selection process appear to be largely subjective judgements, it is felt that little further action can be taken by the Panel. The papers are therefore published to give assistance, and perhaps solace, to those charged with the process.

J.A.DUNSBY,
Chairman,
Ad Hoc Group on Structural Analysis Computer Programs.

CONTENTS

ROCKWELL INTERNATIONAL'S SUBCOMMITTEE FOR COMPUTERIZED STRUCTURAL ANALYSIS

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SUMMARY

The proliferation of large scale structural analysis programs prior to 1973 led to the formation of Rockwell's Ad-Hoc Subcommittee for Computerized Structural Analysis (SCSA). This paper describes how the Ad-Hoc SCSA scoped the task of evaluating the computer programs, how it developed the basis for its evaluations and recommendations and presents tables that define the grading system that emerged. It also describes the compilation of the final report which still serves as a guide for the permanent SCSA formed in 1974. The SCSA formed ASKA and NASTRAN Configuration Control Boards to control the maintenance and development of the programs. The function of these boards in certification of the computer programs and the function of the SCSA in Rockwell Group Services Project reviews are discussed. Finally, some recommendations are made to those who must select computer programs from those that are available.

INTRODUCTION

In the years following 1966, when Computer Sciences Corporation, with MacNeal Schwendler and Martin Baltimore as subcontractors, started the development of NASTRAN, there was a proliferation of large scale structural analysis programs. Boeing's ATLAS program, Mc Donnell Douglas' FORMAT program, Mechanics Research's STARDYNE program and the Institute for Static and Dynamic Analysis of Aerospace Vehicles' ASKA program are examples (see Reference 1 for a survey of some 500 such programs). Of the two methods that were applicable to large scale finite element models of structures, namely the force method and the displacement method, the latter emerged as the successful one and is now used in most general purpose programs. On the other hand the force method has such merits as greater efficiency in special applications that make it the preferred one for these special cases.

NASTRAN eventually came to use only the displacement method and was released to the public in November 1970. However, it had many limitations at that time so Rockwell acquired ASKA for use on its major systems and first applied it to the wing structure of the B-1. Even though various improvements of ASKA were still being received in July 1972 when the authorization to proceed with the Shuttle was received at the Space Division, Rockwell decided to use it for the entire development because of ASKA's multi-level substructuring capability. Several other methods had been mechanized to analyze thin shells, thick shells, piping systems, composite structures, etc. Still other programs had been generated to pre and post-process data that were used by the main processors; some of these were for such special purposes as fatigue and fracture mechanics, aero-elastic analyses, etc.

At about this time plans were being made to integrate large scale steady and unsteady aerodynamics programs and thermodynamics programs with the structural analysis programs, using a master program and interactive graphics to interface between them to speed up the design process. Because of this continuing growth of scope of computer programs, it was considered advantageous to form the Subcommittee for Computerized Structural Analysis (SCSA).

The Ad-Hoc Subcommittee for Computerized Structural Analysis

In February 1973 Rockwell International's Structures Panel formed the Ad-Hoc SCSA. The charter contained the following paragraph:

> The objective of the subcommittee is to review structural analysis computer programs (static and dynamic) existing at the divisions in the North American Aerospace Group and the Electronics Group and to plan and recommend such amendments, additions, and improvements as it shall consider essential for adequate accuracy, efficiency, and turnaround time in applications during the design cycle of aerospace systems. Included in the review shall be ASKA and NASTRAN, the MMLS concept (at the Space Division), the subject of Interactive Graphics, as well as other pertinent static and dynamics programs in the Divisions. The subcommittee will also serve as the North American Aerospace Group/Electronic Group's focal point for ASKA and NASTRAN maintenance and improvement activity, information exchange on all structural software programs, and will generate technical advice and counsel for the use of Rockwell International's representative on the NASA/Industry NASTRAN Advisory Board.

The subcommittee consisted of eight people, two representing the B-1 Division, two representing the Space Division, and one representing each of the Tulsa, Rocketdyne, Columbus and Autonetics Divisions. The author was appointed the chairman and was given approximately five months to accomplish the assigned task.

I. Scope of the Evaluations

The first of eight meetings was held to acquaint all the Subcommittee members with the large scale computer programs that were then under development or in use by government agencies and by Rockwell and other aerospace companies. Special emphasis was placed on the problems users found when using these programs. This meeting ended with open discussions about defining the scope of our evaluations.

The second meeting was held to acquaint the members with the design analyses as conducted at Rockwell and to acquaint them with upcoming computer hardware systems. One type of integration program, intended for preliminary design analyses, was under development at the B-1 Division, namely, the Rapid Response Analysis Program for Integrated Design. Another type of integration program, intended for intermediate and final design analyses, was under development at the Space Division, namely, the Model-Modal-Loads-Stress program. The subcommittee heard descriptions of these programs and of the Integrated Programs for Aerospace-Vehicle Design program. The IPAD program was in the conceptual stage and was under development for the NASA.

At the third meeting each member presented his evaluation of the completeness of the research phase tentatively just completed and his recommendations for completing the work of the subcommittee. Eight questions were suggested as a possible format for those presentations:

1. Are RRAPID and MMLS competitors to various levels of IPAD? Is it likely that eventually they will be replaced by IPAD? How much effort should go into synthesizing these systems of programs?

2. Which unsteady and quasi-steady aerodynamics methods should be relied upon to do the loads and flutter analysis jobs?

3. In view of the uncertainty about the impact that future computers (those with virtual memories) will have on the operation of the ASKA program, what level of priority should be assigned for its development and maintenance relative to that for NASTRAN? Do we need both ASKA and NASTRAN?

4. What should be done about the lack of optional procedures for generating reduced order SIC's and consistent mass matrices?

5. What is the future of computer programs that use: a) the force method, or b) a mixed force and displacement method? Could some of the techniques that make certain of these programs extremely efficient be applied equally well to programs that use the displacement method?

6. What can be done to eliminate the difficulties of modifying NASTRAN?

7. Should we recommend establishing a corporate subcommittee of experts in the use of NASTRAN, ASKA, etc.?

8. Who should be assigned responsibility for maintaining the programs on the structures disc pack?

These questions elicited some lively discussions which led to two more questions the subcommittee decided it should answer in the final report:

9. What do we recommend regarding the use of interactive graphics?

10. What is our recommendation regarding user's manuals?

We also decided that we had a large enough set of computer programs to make meaningful evaluations and recommendations.

II. Basis of the Recommendations

At the fourth meeting the members listed the capabilities and limitations of the previously reviewed computer programs and each member listed the key future needs of his division. They separated these needs into one year, three year, and five year needs. (A manifest basis for making recommendations was beginning to emerge.) Members then presented evaluations of the computer programs relative to the key future needs of each of the divisions. They used a form that had been suggested by one of the members and presented these at the fifth meeting. Also, the interim report was read and unanimously approved at this meeting.

An excerpt from the interim report reads:

> The Ad-Hoc Subcommittee has already drawn firm conclusions on certain points. It believes there will be a continuing need for coordinating the in-house development and maintenance of large scale computer programs, specifically, both NASTRAN and ASKA. Coordination is necessary to assure maximum utility for all the groups of users. Also, the Subcommittee is keenly aware that within its short life span it can do no more than base its recommendations on the current state of a technology that is undergoing tremendous changes and growth. Continuing surveillance of the technology will be necessary to a viable program. Therefore, it recommends:
>
> 1. That the Rockwell International Structures Technical Panel establish a permanent Subcommittee for Computerized Structural Analysis.
> 2. That the permanent subcommittee be assigned the responsibility to identify engineer/programmer experts in the use and modification of NASTRAN, ASKA, and other selected computerized structural analysis programs.
> 3. That the function of a configuration control board of computer programs in multi-divisional use be assigned to the subcommittee.
> 4. That improvements be made of pre- and post-processors for NASTRAN and ASKA.

III. The Final Report (Reference 2)

The group spent a considerable part of the sixth meeting in a workshop type of preparation of composite evaluation charts of the twelve selected computer programs. These were selected, of course, from programs available at nominal cost to Rockwell. Two systems of computer programs, MMLS and RRAPID were also evaluated but not included on the evaluation charts. These charts are presented here as Tables I through IV which, with some study, should be self explanatory. It should be remembered that these evaluations were made in early 1973, and there have been some significant improvements made to some of the programs since then.

The charts list evaluations of specific items in the following categories:

1. Computer hardware requirements and compatibility with future hardware.
2. Levels of analysis requirements that are satisfied by the program.
3. Probability that the program will be maintained and further developed.
4. Adequacy of pre- and post-processors.
5. Adequacy of documentation.
6. Adequacy of library of structural elements.
7. Efficiency of the program.
8. Capability to perform structural dynamics analyses.

The narrative descriptions and evaluations of the programs were all done in the following format:

a. Program Description and Capabilities
b. History of Applications
c. Personnel Availability to Maintain and Develop the Program
d. Users; Identified by Division
e. Limitations
f. Documentation

The conclusions and recommendations were compiled at the seventh meeting. Also, we decided that the final report should contain the answers to the ten questions we had posed, and that the evaluations of computer programs and recommendations for additional work should be presented in both narrative and tabular form; the latter table should list projects in prioritized order. Two more workshop type meetings were held to compile and proofread the final draft.

The recommendations in the interim report were reiterated in the final report along with the other recommendations. The final report was well received by the Structures Panel and by Corporate executives and it was used to define the Group Services Projects that are performed as corporate efforts. After some delay, caused partly by reorganization of the corporate structure, the permanent SCSA was formed.

The Permanent SCSA

In December 1974 the Rockwell Structures Technical Panel authorized the permanent SCSA. The charter starts as follows:

> Because of the need for more interdivisional cooperation among structural analysts to share information, expertise, computer programs, program maintenance and program development it is considered advantageous to establish a Subcommittee for Computerized Structural Analysis. The subcommittee will identify the engineer/programmer experts it believes are qualified to satisfy these needs and the subcommittee will act as a permanent board to control the improvements and development of computer programs in multi-divisional use.
>
> Objective
>
> Implement the general recommendations contained in the final report of the Ad Hoc Subcommittee for Computerized Structural Analysis (report no. NA73-556), as modified by action of the Structures Technical Panel (Addendum I to NA73-556).
>
> Monitor the recommended development effort for those programs which the Structures Technical Panel has selected for Group Service action.
>
> Maintain surveillance of changes to the key needs of the divisions relative to impact on the objectives of the Subcommittee.

As expected, there were many unsolved problems that had accumulated since the dissolution of the Ad-Hoc Subcommittee so the first year was a very busy one for the SCSA. One of the problems was a continuing lack of adequate documentation and other types of communication by the program developers and the user community. Another, was that the members felt that the number of members was not weighted properly, either relative to the number of the users at the divisions or relative to the technical disciplines of the users. As a result the membership was increased by two representing the B-1 Division and two representing the Space Division. This group then re-examined its recommendations of nearly two years past, made a few changes in emphasis but essentially reiterated the recommendations of the Ad-Hoc Subcommittee. The group also restated its recommendation that Configuration Control Boards be established for both NASTRAN and ASKA and that each of the participating divisions be represented on the boards.

I. ASKA and NASTRAN Configuration Control Boards (CCB's)

Rockwell has a documented procedure which authorizes these boards and also establishes their function and reporting level. Following the authorization the SCSA drew up two documents for each board: 1) Research and Engineering Standards - ASKA/NASTRAN Program Configuration Management Plan, and 2) Research and Engineering Procedures - ASKA/NASTRAN Program Configuration Management. These documents were approved and implemented in mid 1976.

The subcommittee decided early in the life of the CCB's that each division member must have the freedom to copy the "standard" versions and modify the copies for special purposes. Otherwise, the "standard" version is used throughout the divisions that have access to the computing center.

The NASTRAN CCB recently received level 16.0 of NASTRAN from CØSMIC. This release represents the turning point in the comparative utility of NASTRAN because of its new capability to perform multi-level substructuring. It also points up the continuing need for the CCB and the subcommittee, as computer programs continue to be developed.

The operation of the NASTRAN CCB is described in Reference 3, from which the following paragraph was taken:

> The representatives of the participating divisions are the members that evaluate the proposed changes for impact to an on-going project. They make recommendations for improvements and submit developments for incorporation into the Rockwell NASTRAN program. They submit recommendations for inclusion in the NASTRAN Group Services statement of work proposal. Each representative serves as a focal point at his respective division for dissemination of NASTRAN documentation, the initial evaluation of NASTRAN user's problems, and the coordination of change requests submitted to the CCB.

One of the CCB's function is to certify any modifications made to the Rockwell standard version of the program. Much of the material in the next two paragraphs was taken from Reference 4.

Complete certification of large scale computer programs is the elusive goal of all software engineers. However, in a recent conference on computerized structural analysis, the U. S. Bureau of Standards indicated that it took upward of 10 manhours of effort to certify a "small" computer program. To undertake such a certification effort the version of the program is usually frozen while the prescribed checks are being made. A more practical approach in industrial usage is to accept a probabilistic certification, namely debugging pilot versions. This approach was taken to evolve present day FORTRAN compilers and to evolve the NASTRAN program itself.

The procedure followed at Rockwell to "certify" the NASTRAN and ASKA programs is to verify that the set of demonstration problems supplied by COSMIC, as well as a set of benchmark problems developed at Rockwell, yield correct solutions. A constant effort is made to include in this set of benchmark problems a spectrum of production problems that have been encountered and solved at Rockwell, plus those that test the various capabilities of the programs. The goal is to ensure the highest probability of success before the modified versions are released for production use.

II. Group Services Project Reviews and Recommendations

The SCSA assumed the job of performing the overall technical review of Group Services Projects related to structural analysis. It also concluded that to perform the review adequately, a much more detailed and timely job of reporting by the Project Managers was necessary. Part of the requirement is that the SCSA must make its recommendations six months in advance of funding allocations, and must base those recommendations partly on past performance of the Project Manager.

When formulating this year's recommendations for FY '79 Projects, the SCSA observed that even though it is apparent that much needs to be done in the field of interactive graphics, it is proceeding very slowly because of lack of necessary hardware.

III. Future Activities of SCSA

Another committee at Rockwell that has responsibility for acquisition of computing hardware (the Engineering Computing Policy Board), has addressed itself to the shortage of interactive graphic hardware and the SCSA will be coordinating its activities with their's during the hardware acquisition.

The SCSA will continue its annual review of Group Services Projects and make recommendations for maintenance and development of NASTRAN, and probably just maintenance of ASKA. It will also conduct at least biennial reviews of the key future needs of the represented divisions of Rockwell; more often, when major projects are cancelled or acquired.

Recommendations

At the risk of being pedantic, the following recommendations are made to those who have the job of selecting computer programs.

1. In the interest of making unanimously endorsed and meaningful recommendations, keep the Ad-Hoc Group small. Rockwell's Ad-Hoc group had nine members and we had to make a deliberate effort to rework each recommendation until all members could endorse it. A much larger group might never have done it.

2. Keep the period of performance of the Ad-Hoc group short in the interest of making a concentrated effort to accomplish its task.

3. Define the immediate, intermediate and long range needs of the community the Ad-Hoc group represents and start small when defining that community.

4. By means of a preliminary evaluation, select the smallest group of computer programs that will provide flexibility of choice after a detailed evaluation. Both evaluations should be made in terms of established needs.

   The grading system shown in the Tables is suggested as one that is general enough so that a group can arrive at a consensus.

5. Document everything that led to the recommendations. Years later it will help put the recommendations in perspective.

These are recommendations to those who must select from the libraries of programs. Those who accumulate the libraries have different objectives, and they may approach them in much different ways than outlined above.

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1. Pilkey, W., Saczalski, K., and Schaeffer, H.; "Structural Mechanics Computer Programs", University Press of Virginia, 1974.

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3. Mock, W. D. and Narayanaswami, R.; "Management of NASTRAN Development and Maintenance in a Multidivision Corporation", Rockwell International Report NA-77-867, October 1977.

4. Narayanaswami, R., "Integration and Certification of General Purpose Programs in a Multi-Division Corporation", delivered to the Fourth International Seminar on Computational Aspects of Finite Element Methods, August 1977.

5. Mock, W. D. and R. E. Allison; "Finite Element Model Substructuring Considerations", Rockwell International Report TFD-78-355, June 1978.

TABLE I

STATUS OF COMPUTER PROGRAMS

STATUS**	APSA/ APSAC	AVCO	STAGS	BOSOR3	RNAP	RRAP	STAR DYNE	MESA	CLASP	NARSAP	NASTRAN* 15.1	ASKA* 4.3	FEM*	SLAGS*
Number of Using Divisions	2	2	2	2	3	3	2	1	2	3	5	3	1	1
Documentation	A	A	M	M	M	A	E	U	U	A	M	M	M	D
Core Size	380K	300K	Var.(A)	300K	350K	490K	300K	100K	450K	450K/ 550K	300K	430K	310K	330K
Automation	A	A	M	A	M	M	A	M	E	E	M	A	A	A
Economy	A	E	A	?	A	A	A	E	E	E	M	M	E	E
Ease of Use	A	M	A	M	A	A	E	A	A	A	M	A	A	A
Number of program experts	3	3	0	0	3	1	1	1	2	4	2	3	2	1
Number of users	40	25	2	4	10	10	10	3	30	18	20	90	35	20
EVALUATION OF PRE-PROCESSORS														
	(IN)	(IN)	(IN)	(IN)	(IN)		(IN)	(EX)		(IN)	(IN)	(IN)		
CAPABILITY TO GENERATE:														
Connected elements & coord	A	A	M	A	-	-	A	M	-	E	-	M	A	-
Structural Weights	-	-	-	-	A	-	A	-	-	A	A	-	-	A
Node point loads	A	A	M	A	M	-	A	A	-	M	A	M	-	A
Aerodynamic control points	-	-	-	-	-	-	-	-	-	-	-	-	-	A
Thermal data	A	A	M	A	-	-	A	-	-	D	-	-	-	A
CRT plots	A	A	?	?	A	-	A	A	-	E	A	U	A	A
Interactive graphics	-	-	-	-	-	-	-	-	-	-	-	-	D	D
Bandwidth minimization	-	-	-	-	-	-	E	-	-	E	-	-	M	-

E: meets all known requirements
A: meets most requirements
M: meets some requirements
U: does not meet requirements
D: under development
UL: unlimited
- none
? insufficient experience to evaluate

*FEM and SLAGS are external pre-processors currently operational to ASKA and being adapted to NASTRAN. The others are pre-processors to the identified main processors; internal (IN), or external (Ex).

**Status information on pre-processors, post-processors, and main processors are identical.

TABLE II

EVALUATION OF POST-PROCESSORS

CAPABILITY TO GENERATE:	APSA/ APSAC (EX)	AVCO (EX)	STAGS (EX)	BOSOR3 (IN)	RNAP (IN)	RRAP (IN)	STAR DYNE (IN)	MESA (Both)	CLASP	NARSAP (IN)	NASTRAN 15.1 (EX)	ASKA 4.3 (EX)
Response and mode plots	-	-	?	-	A	A	A	-	-	-	A	-
Response and mode movies	-	-	-	-	-	-	-	-	-	-	-	-
Stress Contour plots	A	-	?	-	-	-	-	-	-	-	-	M
Static deflection plots	A	A	-	M	-	-	A	A	-	A	A	A
Stress averaging	-	-	-	-	-	-	-	A	-	-	-	A
Static loads plots	-	-	-	M	-	-	A	-	-	A	-	M
Shear flow	-	-	-	-	-	-	-	A	-	E	-	M
Superposition and factoring	-	-	-	-	-	-	A	-	-	A	A	E
Rotation of stresses and loads	M	-	-	-	M	-	-	A	-	-	-	M
Beam stresses	-	-	-	-	M	M	A	-	-	-	A	D
Plate max. principal stress	A	M	-	-	-	-	A	A	-	-	-	A
Diagonal tension analysis	-	-	-	-	-	-	-	-	-	-	-	-
Max. stress search	-	-	-	-	-	-	A	M	-	E	-	A
Criteria search	-	-	-	-	-	-	A	-	-	E	-	A
Margin of safety	-	-	-	-	-	A	-	-	-	A	-	D
Fatigue analysis	-	-	-	-	-	A	-	-	-	-	-	-
Fracture mechanics analysis	D	-	-	-	-	-	-	-	-	-	-	-

TABLE III

EVALUATION OF MAIN PROCESSORS - STATICS ANALYSIS

CAPABILITIES:	APSA/ APSAC (FE)*	AVCO (FD)	STAGS (FD)	BOSOR3 (FD)	RNAP (FE)	RRAP (Modal)	STAR DYNE (FE)	MESA (FE)	CLASP (FM)	NARSAP (FE&FM)	NASTRAN 15.1 (FE)	ASKA 4.3 (FE)
Axial elements	-	-	-	-	E	-	E	A	E	A	E	E
Beams - straight	-	-	-	-	E	-	E	-	E	-	E	E
Beams - curved	-	-	-	-	A	-	-	-	-	-	-	-
Plates - lower order	A	-	-	-	M	-	A	A	M	A	A	A
Plates - higher order	-	-	-	-	-	-	-	D	-	-	-	E
Shells	-	A	?	A	-	-	-	-	-	-	M	A
Solids	-	-	-	-	-	-	A	-	-	-	M	E
Rings	A	-	?	A	-	-	-	-	-	-	M	E
Rigid elements	-	-	-	-	E	-	A	-	-	-	-	-
Max. number of nodal points or regions	1500/ 750(A)	25 reg. (A)	UL(E)	25 reg (A)	200(M)	- -	2500(A)	UL(E)	30K(E)	1998(A)	UL(E)	UL(E)
Max. number of elements or stations	1500/ 750(A)	300/reg. (E)	UL(E)	540(M)	UL(E)	-	9999(A)	UL(E)	50K(E)	7998(A)	UL(E)	UL(E)
Max. number of loads cases	1(A)	1(M)	1(A)	1(A)	UL(E)	-	UL(E)	UL(E)	86(A)	300(E)	UL(E)	UL(E)
Max. number of materials	15(A)	12/reg(E)	?	25(A)	UL(E)	-	250(E)	UL(E)	10(M)	90(A)	UL(E)	UL(E)
Max. bandwidth	108(A)	UL(E)	UL(E)	UL(E)	250(M)	-	15000(A)	UL(E)	100(A)	240(A)	UL(E)	UL(E)
Bandwidth minimization	-	-	?	-	-	-	E	-	-	-	-	-
Geometry representation	A	A	E	A	A	-	A	E	M	M	E	A
Substructuring	-	-	-	-	-	-	M	M	A	-	M	A
Buckling	-	-	A	A	-	-	-	-	-	-	M	D
Creep	-/M	-	-	-	-	-	-	-	-	-	-	M
Plasticity	-/A	-	-	-	-	-	-	-	-	-	M	M
Large deflections	-/A	-	-	?	-	-	-	-	-	-	A	D
Non-linear loads	-/A	-	M	A	-	-	-	-	-	-	A	-
Non-linear materials	-/A	-	?	-	-	-	-	-	-	-	A	M
Orthotropic materials	A	-	A	A	-	-	-	M	-	-	A	E
Temperature dependent mat'ls	-	-	A	-	-	-	-	-	-	-	M	-
Error messages	A	A	?	U	M	-	A	M	E	A	M	A

* FE - displacement method,
FM - force method
FD - finite difference method

TABLE IV

EVALUATION OF MAIN PROCESSORS - DYNAMICS ANALYSIS

CAPABILITIES:	APSA/ APSAC	AVCO	STAGS	BOSOR3	RNAP	RRAP	STAR DYNE	MESA	CLASP	NARSAP	NASTRAN	ASKA
EIGENSOLUTIONS:												
Max degrees of freedom	-	-	-	540	125(M)	-	6000(E)	-	-	-	UL(E)	?
Stiffness matrix reduction	-	-	-	?	A	-	A	-	-	-	A	A
Consistent mass reduction	-	-	-	?	D	-	M	-	-	-	M	?
Automated component modes	-	-	-	-	-	-	-	-	-	-	M	-
CRT plots	-	-	-	?	A	-	A	-	-	-	A	-
Error messages	-	-	-	?	M	-	A	-	-	-	M	?
AEROELASTIC ANALYSES:												
SIC/AIC coordinate transformation	-	-	-	-	-	-	-	-	-	-	D	-
Unsteady aerodynamics	-	-	-	-	-	-	-	-	-	-	D	-
Static divergence analysis	-	-	-	-	-	-	-	-	-	-	D	-
Control effectiveness analysis	-	-	-	-	-	-	-	-	-	-	D	-
CRT plots	-	-	-	-	-	-	-	-	-	-	-	-
Error messages	-	-	-	-	-	-	-	-	-	-	-	-
STEADY-STATE RESPONSE ANALYSES:												
Max. degrees of freedom	-	-	-	540(A)	-	108(A)	A	-	-	-	UL(E)	?
Max. number of modes	-	-	-	?	-	A	A	-	-	-	UL(E)	?
Base excitation	-	-	-	-	-	A	A	-	-	-	M	?
Force excitation	-	-	-	-	-	A	A	-	-	-	A	?
Random uncorrelated excitation	-	-	-	-	-	A	A	-	-	-	M	-
Random correlated excitation	-	-	-	-	-	-	-	-	-	-	-	-
Unsteady aerodynamics	-	-	-	-	-	-	-	-	-	-	D	-
CRT plots	-	-	-	?	-	A	A	-	-	-	A	-
Error messages	-	-	-	-	-	M	A	-	-	-	M	-
TRANSIENT RESPONSE ANALYSES:												
Max degrees of freedom	-	-	-	-	-	108(A)	A	-	-	-	UL(E)	?
Max number of modes	-	-	-	-	-	A	A	-	-	-	UL(E)	?
Base Excitation	-	-	-	-	-	A	A	-	-	-	M	?
Force Excitation	-	-	-	-	-	E	A	-	-	-	A	?
Initial condition	-	-	-	-	-	A	A	-	-	-	A	?
Arbitrary forces vs time	-	-	-	-	-	M	A	-	-	-	A	?
Impulses, step and ramp	-	-	-	-	-	E	-	-	-	-	A	-
Unsteady aerodynamics	-	-	-	-	-	-	-	-	-	-	D	-
CRT plots	-	-	-	-	-	A	A	-	-	-	A	-
Error messages	-	-	-	-	-	M	A	-	-	-	M	?

SELECTION CRITERIA FOR STRUCTURAL ANALYSIS PROGRAMS

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Introduction

This paper is presented on the premise that a prospective user has several candidate structural analysis programs in mind and that their relative merits and demerits are not so obvious as to make selection a fairly trivial matter. It is further supposed that it is required to embark on a fairly formal procedure to select the "best" system in a manner illustrated conceptually in Fig.1. Given a number of candidate systems and informed management, selection could be based on the first and last steps in this procedure, i.e. the initial rejection of totally unsuitable systems and choice from among the remainder on the basis of personal judgment alone. This is a feasible and often-used approach but for the purpose of this discussion a three-stage procedure is assumed

1. Initial screening
2. Formal assessment
3. Management decision

The paper is aimed primarily towards users in large industrial organisations and makes particular reference to the use of structural analysis programs in inter-company and international joint projects.

1. INITIAL SCREENING

There are, at present, many structural analysis programmes available, either for commercial sale or rental, or for distribution through public bodies. Of these there are at least 15 systems fairly widely available in NATO countries which are credible contenders for use by major companies. Furthermore, most large companies today have an in-house system of their own or have access to such a system in a partner organisation. The problem of selection is therefore a very real one but it is not, of course, necessary to cut the choice down to a single system. Often a company will opt to use and maintain two or more systems whose strengths lie in different areas, so that together they provide adequate capability.

Before discussing the initial screening for acceptable candidate systems it is worth making an important philosophical point. Most of the currently available major systems are good and are developed by competent and enthusiastic teams. A large amount of time and effort could be spent in drawing up a detailed comparison between such systems only to obtain an inconclusive result and intuitive judgment would still be used in the final decision. The approach suggested here is to elicit pertinent facts with as little effort as possible, to reduce contenders wherever possible by avoiding major obstacles to successful implementation and to make a final decision on the basis of judgment supported by an objective assessment of the facts. TIME WILL BE BETTER SPENT IN CAREFUL IMPLEMENTATION OF ANY GOOD SYSTEM THAN IN CONDUCTING AN OVER-ELABORATE COMPARISON BETWEEN NEARLY EQUAL CONTENDERS.

The first step in the process is to eliminate those systems which do not satisfy important user requirements and cannot readily be adapted to do so. The criteria used at this stage include the following:-

Availability
- to potential users on a sound commercial basis
- in the future consistent with National policies

Compatibility
- with the company's computer configuration (and those of partners)
- with the operating system and software used by the company
- with the mode of operation demanded by the user

Capability — to handle problems of the types required

Capacity — to cope with the size, complexity and throughput needed

Commercial constraints
- consistency with national or company policy;
- cost limitations (unlikely to rule out a system at this stage)

It is advisable to seek assurance of the continued availability of rented or leased systems and bureau services and of technical support, irrespective of method of acquisition, for as long as the user thinks necessary. This is particularly true of

programs supplied through public institutions in other countries, which can be subject to changing political directives.

Compatibility with operating systems and software can obviously be achieved at a cost - at this stage it would be appropriate to retain an otherwise satisfactory candidate system and simply record the software modification cost for use in subsequent assessments. Incompatibility with the computer hardware should normally be regarded as reason for rejecting a candidate system outright. The cost of rewriting incompatible code is too high to justify further attention unless there is no other possible candidate system.

Again, if the user organisation is set up in such a manner that interactive operation from terminals is essential, there is no point in giving detailed attention to systems which cannot conceivably operate in this mode.

Capacity may be very hard to judge by discussion with the potential supplier alone. It is best, if in doubt, to try to find other users and obtain first hand experience. Failing this ask the supplier to demonstrate the ability to handle marginal tasks.

The starting list of candidates may by now have been reduced to a manageable number and the next section deals with their more detailed appraisal.

2. FORMAL ASSESSMENT

The three principal elements in the formal assessment of competing programs are described in Fig.1 as

- Selection criteria
- Ranking method
- User experience

The main purpose of this paper is to deal with the criteria but before doing so a few words on the other items are appropriate. It is already evident, and will quickly become more so, that any comparison will involve differing levels of performance against criteria which have, superficially, nothing in common. The basic dilemma in all formal assessments is to compare the dissimilar in some meaningful, overall way. If the user's task is sufficiently explicit, many of the conflicting requirements can be reduced to the two main programme control factors

- what is the total cost of doing all the jobs needed?
- what will be the elapsed time (or the rate of turnover)?

In this situation it is only necessary to make one major subjective judgment (the monetary value of time) to reduce all assessments to a common currency.

More often no such facile solution presents itself and the only way to introduce formality into the assessment is to make several independent assessments of "value" to the organisation of good performance against specific criteria. These can be assessed by a "points scheme" or by any grading symbols, whereupon a further, subjective, weighting judgment must be applied to obtain an overall ranking. The result is multiply suspect and only the very unwise would use such a ranking as the only basis for choice. However, this approach, used by people of good sense, often produces results which are not unduly sensitive to substantial changes of individual weightings. A competent manager will ask for an assessment of sensitivity to changes in the more significant parameters and will then have a useful background for the exercise of his judgment. These points will be illustrated later by a simple example.

The experience of other users in a similar type of business is invaluable in supporting or modifying the claims of suppliers regarding the usefulness of a program in practice. In particular, only a user can comment adequately on the ease of use of a system, the intelligibility of its documentation and the amount of internal support which it demands in order to function satisfactorily.

The selection criteria are subdivided for convenience into three groups, depending upon the principal objectives which they aim to satisfy. These are described in Fig. 1 as:-

2.1 Technical Specification
2.2 Operational Criteria
2.3 Commercial Criteria

2.1 Technical Specification

The prospective user will have a range of known tasks which must be performed in a routine manner, some fringe tasks which he expects to perform occasionally and some notion of developments which are likely to be needed in the future. Unless his tasks are very straightforward and fall into a pattern already well established by other users it is unlikely that all his present and foreseeable future requirements can be met

adequately by one system. In preparing a specification the user must consider his priorities so that he can grade features between "essential" and "desirable developments" and look for development potential in the system itself and in the team of people supplying it.

It is not proposed to present a comprehensive catalogue of features which a prospective user may seek in writing a specification. The following general headings and notes draw attention to some aspects of the specification which may not be immediately obvious.

a) Types of Analysis

All users in aviation are likely to require linear static analysis, eigenvalue analysis and some basic dynamic capability and most systems provide these. The other features required will depend on the user's principal needs and priorities. Basic analytical capability is not easily added to an existing system and if for example a good non-linear fracture mechanics or transient response capability is an essential part of the requirement the user should not settle for less.

It is very useful to have a simple macrolanguage and associated data structures, (e.g. a matrix scheme) such that the user can program his own sequences of operations to supplement those provided as standard and within the system.

It may be very convenient to be able to perform non-structural calculations(e.g. heat transfer, fluid motion etc.) using the same basic analysis formulation but very often two systems, each optimised for its own function, will be better than one.

b) Element Library

Most commercial analysis systems have a good basic element library and the user should look for the simplest and most consistent family of elements to perform the functions he requires rather than the largest and most exotic collection of analytical frills. The ideal elements are usually those which are simple to specify and interpret and which satisfy reputable tests (such as the patch test) for consistency and convergence.

The day-to-day user of a commercial analysis program is unlikely to be a finite element analysis specialist. Such users, in my experience, value intelligibility and freedom from occasional aberrations more highly than analytical refinement. The big library is an asset, but only if the basic every-day elements are sound.

c) Constraints and Interconnections

Most analysis systems have been conceived with the objective of solving single, well defined problems with clear-cut loading conditions and supports and a pre-determined interconnection with other structures. Real structures, on the other hand, are often complex in their definition and interconnection and it is frequently necessary to solve the same basic problem with different sets of boundary conditions and modified coupling between structures.

Most modern users will require substructuring facilities i.e. the ability to break structures down into smaller units, to analyse them independently with simplified or approximate boundary conditions and to interact adjoining structures in a global analysis when convenient. It is worth giving this aspect a good deal of thought in specification formulation because few systems are well structured from this point of view and some are extremely cumbersome to use in the substructure mode.

It is often helpful to take account of symmetries about one or more axes or planes in formulating practical analyses. The user may require facilities for dealing with planar or cyclic symmetry, (axisymmetry is usually treated quite separately in a special 2-dimensional formulation) and for introducing symmetric, antisymmetric or repeated boundary conditions. A particularly searching requirement is to link symmetric and asymmetric substructures by simple routines.

In many analyses it is very convenient to be able to introduce special support conditions and interconnections or releases between adjacent degrees of freedom. Common requirements are to interconnect non-coincident nodes, to rigidly connect groups of nodes, to release specific degrees of freedom (mainly hinges) and to eliminate near-singularities by coupling of freedoms. User experience is needed to appreciate the importance of these points and to frame a detailed formal specification. It is worth looking for the following specific features:-

- single-point constraints in any direction
- multipoint constraints linking any number of degrees of freedom
- offset node and rigid element facilities
- decoupling of specific degrees of freedom (or coupling in selected freedoms)

In all the above cases - substructuring, symmetry and constraints-a good analysis system will itself calculate all necessary connectivity and constraint matrices. External calculation of coupling data, using information already supplied in the basic geometry data, is both time-wasting and prone to serious errors. A regular user will

need to add his own preprocessor routine to a system which makes such demands.

d) Input, Output and Interfaces

Given an adequate analytical capability, the features that will most affect the users are the data preparation and the output formats. Data preparation is fundamentally a time-consuming chore and few people combine the intelligence and experience needed for good modelling of real problems with the patience and care needed to avoid errors when compiling routine data. Many analysis systems now have aids to data preparation and checking but these will rarely meet all the needs of the regular user in a specialised field. It is highly desirable that an analysis system should be structured, both in data formats and in program architecture, so that the additional pre- and post-processor routines can be added by the user community. The interfaces must be well-defined and stable, i.e. they must not change in any way between one version of the main program and another.

Some particular features which users will find valuable are:-

- Program and data structures which permit breaking complex structures down into convenient, handleable units, whether they are to be analysed as substructures or not.

- Corresponding presentation of intermediate data for checking and output for ease of interpretation.

- Unique specification of all physical data (i.e. no duplication of any physical quantities in different blocks of data). In the case of substructures this rule may be violated at common nodes provided there is a clear hierarchy of data integrity or a fail-safe checking procedure.

- Recovery of complete data at the output stage (i.e. all the fundamental output such as deflections or stresses plus input or intermediate data sufficient to derive all possible information consistent with the analytical model). This feature is very important if the analysis is to be used as part of an automated design or optimisation procedure which might require forms of output not available as standard.

- Input and output consistency checks; in particular geometry and topology of the input and equilibrium and compatibility of the output. (In displacement analyses, local and global equilibrium often gives an excellent indication of numerical accuracy).

e) Test Problems

An experienced user will have discovered a number of tricky problems relevant to his normal business which will serve to check for pitfalls encountered with earlier systems. An alert new user should also formulate some trial problems both for gaining experience in data preparation and interpretation and to find out how competently an analysis functions in difficult circumstances. Some types of problem which can be effective in showing up difficulties or inaccuracies are:-

- Flexure of long, slender beams in their plane - modelled in various ways using bar and membrane elements

- Flat plates under pressure, modelled in various patterns using flexural plate elements

- Flat plate stability, various element patterns

- Large deflection of uniform slender beams with various ways of modelling

- Impact of rods and beams with various modelling patterns

The above can all be checked out amongst themselves and with standard solutions in the literature. Other types of test can be carried out simply to see whether any solution is obtainable at all and to apply basic consistency checks. The most searching tests will be those which either expose fundamental weaknesses in current theory or involve near-singularities which exaggerate numerical inaccuracy. Some examples are

- Shallow shells, in particular shells analysed as membrane facets with one or more nodes unsupported in the direction normal to the surface (this can in special cases give true singularities which should cause a run failure) and shells modelled as flexural elements where rotation about surface normals needs special treatment.

- Locally stiff structures on relatively very flexible supports e.g. a structure of (stiff) membrane elements simply supported on very weak springs (keep reducing spring stiffness until difficulties or serious inaccuracies arise).

2.2 Operational Criteria

Whilst the prospective user might find it very difficult to make a balanced judgement between candidate systems on technical grounds alone, the practicality of using the systems on specific computer installations can vary enormously. The following

considerations are often dominant in making the eventual decision.

a) Computer Configuration and Capacity

It can be assumed; at this stage, that any system totally incompatible with the users' computer-configurations has been eliminated from immediate consideration. It is important to establish the operational limitations, if any, of candidate systems in relation to all the computer installations on which they are to run. This is especially true where different computers are being used by separate groups of users in a single project. Without attempting an exhaustive list, the following are some factors which must be established for each candidate system

- Minimum CPU and memory for efficient operation

- Number and capacity of supplementary storage channels (disc packs, tape drives etc) for normal operation

- Other peripherals needed for normal execution and for full exploitation (e.g. plotters, graphic stations, VDU terminals etc)

- Level of transportability of basic and intermediate data between different computer types (collaborative situations)

- Possible execution modes for (a) normal and (b) exceptional size jobs e.g. continuous batch, interrupted batch, RJE batch, RJE on-line, interactive on-line, external bureau etc.

Any deficiencies of hardware configurations in relation to a given analysis system should be expressed in simple terms such as cost-to-remedy. Such a cost debit against an analysis system may well be offset against improvements in technical/operational performance compared with other, less demanding systems.

b) Execution Speed

Structural analyses formulated in direct nodal geometry, nodal loading and element data terms use very large amounts of input and output data so that overall execution times depend on external data transmission as well as mathematical operations and internal data handling. This makes times and costs very dependent on computer size and configuration and rather difficult to estimate by general algorithms. It is often found that efficiency is also dependent on the sequencing of data and this is an important factor to establish at an early stage. The prospective user should know not only whether sensitivity exists but also whether the rules (or automatic resequencing subroutines) exist for obtaining efficient sequences. If the supplier cannot answer the question this should be a warning that he lacks detailed knowledge of this system's performance in practice.

Again, structural analysis, heat transfer and particularly dynamic response and fluid mechanics analyses are often very large individual calculations. The user should specify the approximate size of the largest jobs he can envisage and find out whether they can be executed within the normal operating times likely to be available. If they cannot be executed in a single pass, then efficient termination and restart procedures are essential.

Any user who intends to carry out iterative calculations such as large deflection analysis, transient analysis or optimisation must aim for single-pass execution times in seconds or minutes for normal size jobs in order to have any hope of acceptable overall solution speeds.

Finally, the elapsed time from job conception to use of results depends much more on the data preparation,checking and interpretation times than on the execution of the analysis proper. The user may wish to use pre- and post-processor routines supplied as part of the analysis package or add his own routines in order to speed up and reduce errors and tedium in the extraneous stages. In the former case he should give as much attention to evaluation of the routines available as to the analysis system itself. Their simplicity and effectiveness will make or mar the success of the system as a whole.

If the user wishes to add his own routines (and most will eventually reach this position) then it cannot be over-emphasised that the structure of the basic program and the interfaces must be such as to give the user ready access to intermediate data and, as already mentioned, they must remain stable as the program evolves to avoid obsolescence or, worse still, inaccuracy in the future.

c) Evolution and Support

The state of the art in finite element analysis is still changing rapidly and a system which looks good today may seem mediocre tomorrow. Likewise, with computer hardware, the system which functions well on today's computers may be quite inappropriate to the next generation. Reprogramming major systems for incompatible hardware has been perhaps the biggest headache for computer users in the past two decades. Whilst many advances have been made in interchangeable software, the problem is still with us in relation to the 'architecture' of central programs and data base management to make best use of the present-day hardware. We are now approaching one of the major watersheds in

technical computing - the transition from mainframe-dominated multi-user systems to distributed computing using linked, more specialised machines with their own data bases.

The largest and most active finite element software suppliers are recognising this and are adapting their systems accordingly. This is but one example of major evolution which is prohibitively expensive for individual, in-house, development but which can be tackled economically by the multi-customer supplier. In this respect one must judge suppliers by their past performance and by their responsiveness to proposed change. When all the other criteria have been established and several candidate systems still remain this may be the best area for personal judgement. The prospective users and their managers should meet the supplier team, discuss their present and future plans, evaluate the health and vigour of their user support services and make what can only be a subjective judgement of their likely ability to move with the times without disrupting continuity.

Likewise, when things go wrong, as is inevitable in any dynamic system, the supplier team should be competent and able to come to the aid of the user. The cost and management of the total computer analysis facility will be quite different if the user can rely on competent professional support when in difficulties rather than have to build up his own support team to cope with all possible arisings. This is the main reason why commercial software suppliers are usually much more effective than informal software sharing schemes. If the supplier takes responsibility for the integrity of his product this relieves the user of a large insurance investment or of the delays involved in "fire-brigade" actions to rectify unexpected errors. Points to look for here are the existence of an active user community and a well organised system for disseminating information on user problems and their solutions. However, too frequent updates of basic programs for error-correction (as opposed to genuine evolution) should be a warning as to the competence of the supplier's team.

One further important aspect of support concerns the documentation. Any purchaser or hirer of a computing system should be able to stand on his own as regards normal use of the system after initial familiarisation. Documentation must be comprehensive and embrace the engineering user, the specialist programmer and the system support team (where required). It should, hopefully, be easy to read and be well indexed and cross-referenced for easy access to information. These last points are deficiencies in most known documentation, the main difficulty being that manuals are written by involved specialists and read by non-specialists - a classic recipe for a communication gap. It would be an outstanding recommendation of the competence of any team if it could supply documentation which was at the same time technically rigorous and wholly intelligible to non-specialist engineers.

d) <u>Prior Experience</u>

If one or more partners in a joint project already have experience of the use of a particular system this is bound to figure prominently in any assessment. It may have either a positive or negative influence according to how satisfied the users feel with the system they know. Unnecessary disruption of an adequate and efficient system in operation is a managerial crime. Equally, it is folly not to recognise shortcomings in a known system and use these as benchmarks for judging others. Either way, experience is a valuable asset and should be heavily weighted in final assessment.

2.3 <u>Commercial Criteria</u>

Under this heading, direct cost of buying or leasing programs is likely to be a relatively minor consideration. The market is so competitive that any commercial system looks cheap compared with the in-house investment which would be needed to emulate it. Much more important are the support and running costs of the system, any constraints on its use and guarantees of future availability, and support.

a) <u>Costs</u>

Factors to be considered in comparing different systems may include the following

- First cost or initial entry cost of the basic system
- Periodic rental of the basic system
- Supplementary software costs
- Service and maintenance costs
- [Contributions to new development]
- In-house support costs
- Running costs
- Costs of computer enhancement to embody the system.

Contributions to new development are only valid for inclusion at this stage if they are necessary to bring a system up to a competitive standard. In-house support and running costs are the most difficult items to estimate in advance and will therefore

repay the most careful attention; here is another case where the experience of other users is invaluable.

b) Legal and Commercial Limitations

Buying or hiring a commercial analysis system involves a large measure of dependency of the user on the supplier and this in turn requires a good commercial relationship between the two parties. Whilst the supplier can impose few legally enforcible restrictions on the user he may well make quite stringent contractual limitations which it is in the user's interest to observe. For example, the use of the system is likely to be limited to a single site or even a single computer installation unless a special deal involving several sites is negotiated.

The supplier may limit the user's access to the basic source programs to prevent tampering with the internal workings of the system which might in turn invalidate any guarantees of integrity. On this topic, it is as well to establish from the outset, what liability the supplier will accept for deficiencies in the programs supplied. A good supplier will usually undertake to make good any fundamental system defect discovered by a user at his (the supplier's)expense. He is unlikely to reimburse any costs incurred by the user in failing to achieve a correct result.

From the user's viewpoint, the most important criterion under this general heading is likely to be continuity. A user will become involved with an analysis system as a way of life and it becomes increasingly difficult to change rapidly from one system to another. Any user is likely to need a guarantee of on-going support for a system at least 12 months ahead; assurances of development and support over far longer periods, say 5 years, are needed as a basis for proper planning. These factors are especially important when obtaining a bureau service which, in theory, could terminate overnight.

In the collaborative project field a user requires an on-going commitment on the part of his partners. Assurances are likely to be easily obtained, guarantees are unlikely. In any event a consensus agreement on a system is required rather than a unilateral one. This brings us back to a very difficult issue and one which can have a serious impact on real-life decisions. Consensus between partners in different companies and different countries cannot be divorced from feelings of national or corporate loyalty or even political pressure. If such considerations are likely to prove important they should be identified before committing too much effort in a pseudo-scientific evaluation.

3. MANAGEMENT DECISION

The person or team responsible for assessing competing systems will have compared candidate systems on the basis of some or all of the above-mentioned criteria, together with others which may relate to their special circumstances. Unless a clear choice emerges to the satisfaction of all concerned, some formal comparison may be required. It is suggested that this should take one of two forms - a weighted quantitative comparison of system features, or an effective cost summary. In some cases the two may be combined, as previously indicated, into a single figure of merit for each system together with some measure of sensitivity to the more important factors. This is the information on which judgment should be based and if the formal evaluation still remains finely balanced it cannot matter very greatly which system is chosen. A thoroughly subjective judgment based on personal preference or confidence is quite in order.

The paper concludes with a hypothetical example to illustrate some of the points made above. The formal assessment chart in Fig.2 lists only the main headings used in the previous text and each feature is first ranked on a scale of 0-3 according to the extent to which an analysis system satisfies the more detailed criteria under each heading. A weighting factor is used against each feature which is multiplied by the ranking number to give a rating which is then accumulated over all the features.

In this hypothetical case a simple and cheap system A is compared with two more sophisticated systems - B being particularly strong in its operational performance and C in technical performance.

The features rated in the chart are divided into three groups to assist in subsequent judgment. The first consists of factors which are mosly factual and where the ranking sequence can be established with confidence. It is mainly the weighting factor which is open to argument and the sensitivity to this can be assessed by trying different combinations of reasonable factors. In the case shown it makes no significant difference whether the two weighting levels are used or all the rankings are used without weighting. This particular facet of judgment is therefore not unduly sensitive.

The second group consists of features whose ranking depends on a subjective assessment either of future happenings (evolution, legal constraints etc) or of the value of an ad-hoc comparison based on necessarily incomplete or inconsistent evidence (test problems and user experiences). The weighting of these numbers involves a further judgment on the part of the compiler and hence the sensitivity of these factors to personal bias is clearly higher than for the previous group.

Finally, cost has been kept separate so as to isolate the other type of value judgment namely the comparative value of all the other features with basic costs as defined in

the text. This value is amenable to analysis if it is possible to put a cost figure against the enhancement of technical and operational performance to meet the required standards or the direct cost implication of sub-standard performance (e.g. execution speed). In this case the alternative presentation of Fig.3 is likely to be more meaningful.

From Fig.2, clearly system A would be rejected unless the importance of cost has been seriously underestimated. Equally clearly the difference shown between systems B and C is not significant in relation to the possible inaccuracies of many parts of the assessment. This same conclusion is reached if we make very different estimates of weighting factors. Inspection of the chart narrows down the field of judgment for the manager to the following principal issues

Superior range of analysis capabilities and computer compatibility for system B vs superior input/output and interface stability for C.

Better user experience and confidence in the development team for system B.

Lower cost for system C.

Assuming that the relative weighting of the technical issues is reasonably accurate the final judgment comes down to the value placed on confidence in the supplier and his team.

The cost summary, as illustrated in Fig.3 is superficially far more satisfactory than the rather arbitrary points assessment. However it is usually not possible to make the type of cost forecasts needed without extensive experience of the system beforehand. Furthermore, the difference in cost to the user of modifying or extending a complex system himself as opposed to doing the same job with the assistance of the supplier could be very large. But the major deficiency of a cost comparison alone is that it does not reflect confidence in the integrity of the system, the supplier's ability to maintain and develop it or the continued availability of the system except in so far as these are reflected in the allowances made for enhancement and support.

The figures shown, whilst wholly fictitious do illustrate some important points, of which the most obvious is the relatively small proportion of the total operating cost which is attributed to first cost or rental. The level of 5-10% shown here is probably quite typical of a user with a large workload - and these costs only cover the analysis system itself and its direct computer/programming support, not the engineering costs of job execution. The figures have been made broadly consistent with the ratings in Fig.2 so that a cost advantage is shown for system C (it requires less technical enhancement and has lower running costs). This is to be offset against the subjective factors of Fig.2 which clearly favoured system B and which imply that supplier assistance could be expected to cut back the development costs. So the same fundamental management decision remains; the terms in which it is presented (money versus confidence) are rather more clear cut but no more accurate.

Returning to a point made at the beginning, it is likely to be more cost effective to make a judgment at this stage rather than mount a detailed comparative study (by perhaps giving both systems a limited trial run) and defer decision. The time spent in appraisal would be better used in enhancing deficiencies in the chosen system.

ANALYSIS SELECTION PROCESS FIG 1

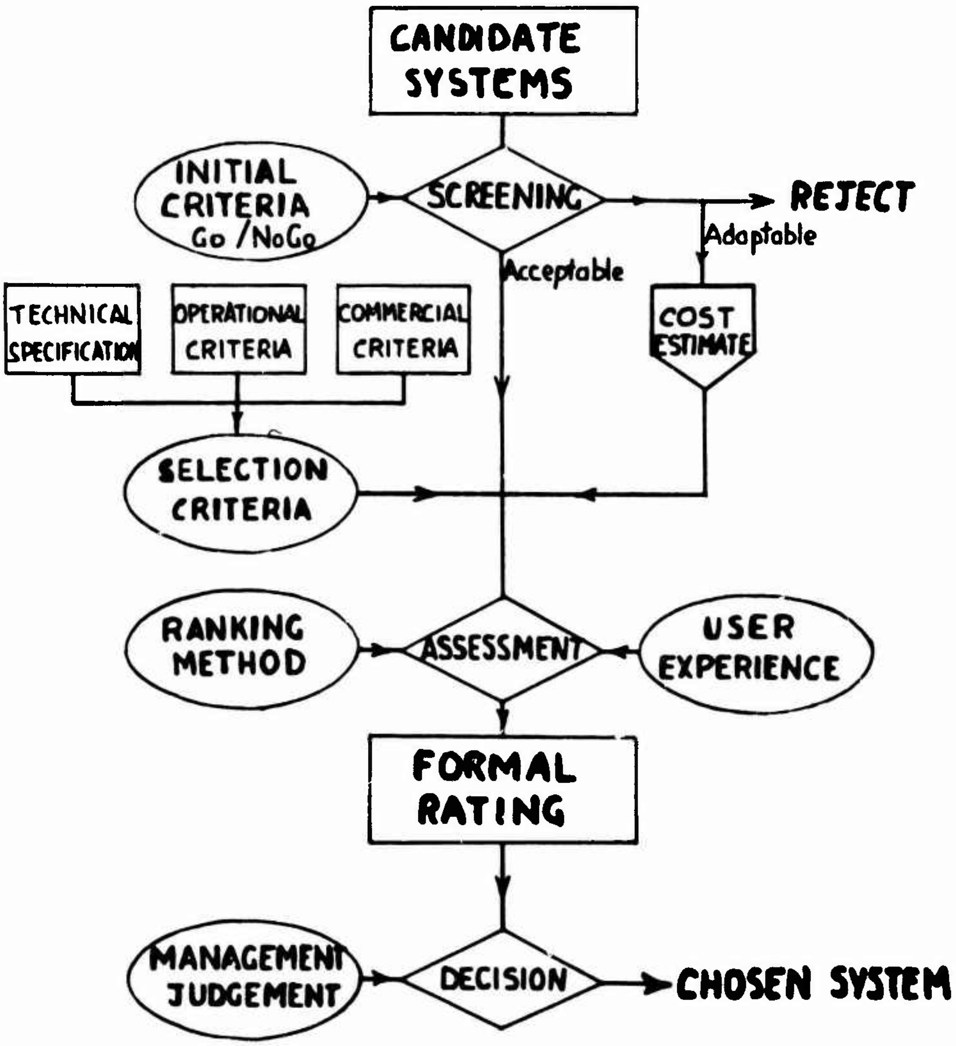

FIG. 2 FORMAL ASSESSMENT CHART

FEATURE	WEIGHT FACTOR	SYSTEM A		SYSTEM B		SYSTEM C	
		RANK	RATING	RANK	RATING	RANK	RATING
TYPES OF ANALYSIS	2	2	4	3	6	2	4
ELEMENT LIBRARY	1	3	3	2	2	2	2
CONSTRAINTS, CONNECTIONS	1	0	0	1	1	2	2
I/O AND INTERFACES	2	1	2	1	2	3	6
COMPUTER COMPATIBILITY	2	1	2	3	6	1	2
EXECUTION SPEED	1	2	2	2	2	3	3
OBJECTIVE FACTORS		(9)	13	(12)	19	(13)	19
TEST PROBLEMS	2	1	2	2	4	2	4
EVOLUTION, SUPPORT	2	1	2	3	6	2	4
USERS' EXPERIENCE	2	1	2	2	4	1	2
LEGAL/COMMERCIAL CONSTRAINTS	2	3	6	2	4	2	4
SUBJECTIVE ASSESSMENTS		(6)	12	(9)	18	(7)	14
SYSTEM RATING		(15)	25	(21)	37	(20)	33
COST RATING	3	3	9	1	3	2	6
COST EFFECTIVENESS RATING		(18)	34	(22)	40	(22)	39

RANK KEY			
3	=	EXCELLENT	ALL CRITERIA SATISFIED
2	=	GOOD	IMPORTANT CRITERIA SATISFIED
1	=	FAIR	ENHANCEMENT DESIRABLE
0	=	POOR	EXTENSIVE ENHANCEMENT ESSENTIAL

FIG. 3 COST COMPARISON CHART

BASIC COST ELEMENT	SYSTEM B	SYSTEM C
FIRST COST, INITIAL ENTRY COST	£10K	£50K
BASIC RENTAL	£30K	0
SUPPLEMENTARY SOFTWARE	£30K	0
SERVICE AND MAINTENANCE	£20K	£20K
BASIC RUNNING COST	£450K	£300K
IN-HOUSE SUPPORT	£200K	£120K
TOTAL BASIC COSTS	**£740K**	**£490K**
ENHANCEMENT COSTS	**SYSTEM B**	**SYSTEM C**
EXTEND ANALYSIS TYPES *	0	£150K
EXTEND ELEMENT LIBRARY *	£80	£60
ADD CONSTRAINT FACILITIES *	£150	£70
ADD & MAINTAIN PRE- AND POST-PROCESSORS *	£250	0
UPGRADE COMPUTER HARDWARE	0	£300
TOTAL ENHANCEMENT COSTS	**£480K**	**£580K**
COST TO SATISFY SPECIFIED CRITERIA	**£1220K**	**£1070K**

* COSTS IF WHOLE JOB IS UNDERTAKEN BY THE USER ALONE (REDUCED IF SUPPLIER AND/OR PARTNERS COOPERATE).

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15. Abstract

The use of computerised techniques of structural analysis is now standard in many branches of engineering. There is, however, a wide range of programs available both commercially and within individual organisations. These programs differ in their capabilities and in their costs and ease of use. The potential user may experience considerable difficulty in selecting a program that is appropriate to his particular class of work.

The paper by Mr. Andrew describes in detail the technical and administrative course of action that has been adopted by a major industrial organisation to select and implement programs that are appropriate to its work. Mr. Taig presents a similar discussion but with perhaps more emphasis on technical issues.

Papers presented at the 47th Structures and Materials Panel Meeting, Florence, Italy, September 1978.

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